PLANT GENETIC RESOURCES

Conservation and Use

UNITED STATES
DEPARTMENT OF
AGRICULTURE

PREPARED BY
NATIONAL PLANT GENETIC
RESOURCES BOARD

PLANT GENETIC RESOURCES: CONSERVATION AND USE

Prepared By

NATIONAL PLANT GENETIC RESOURCES BOARD

Report requested in Secretary's Memorandum No. 1875, Revised, February 23, 1978.

March 1979

TABLE OF CONTENTS

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UNITED STATES DEPARTMENT OF AGRICULTURE
OFFICE OF THE SECRETARY
WASHINGTON, D. C. 20250

February 23, 1978

SECRETARY'S MEMORANDUM NO. 1875 REVISED

NATIONAL PLANT GENETIC RESOURCES BOARD

The Secretary of Agriculture hereby reestablishes the National Plant Genetic Resources Board. The task of the Board is to advise on the assembly, description, maintenance, and effective utilization of the living resources represented by crop cultivars, primitive and wild forms of our crops. These resources are necessary for plant scientists to have the genetic variability necessary to cope with problems of today and the future.

The Plant Genetic Resources Board objectives are to advise the Secretary of Agriculture and officers of the National Association of State Universities and Land Grant Colleges in order to assess national needs and identify high priority programs for conserving and utilizing plant genetic resources including such things as collection, maintenance and description of genetic stocks, and utilization of the stocks in plant improvement programs.

The duties of the National Plant Genetic Resources Board are (1) to inform themselves of domestic and international activities to minimize genetic vulnerability of crops; (2) to formulate recommended actions and policies on collection, maintenance and utilization of plant genetic resources; (3) to recommend actions to coordinate the plant genetic resources plans of several domestic and international organizations; (4) to recommend policies to strengthen plant quarantine and pest monitoring activities, and (5) to advise on new and innovative approaches to plant improvement.

The Board will meet at least twice each year and possibly more often. The estimated annual operating costs are $400 for support; $6,600 for assisting in operation of committee; $17,000 for travel expenses, including per diem or subsistence incurred by committee members and Department employees; $13,000 from sources outside the government; and 0.3 man years. This estimate includes all private and public funds to be spent by or on behalf of the Board.

Members of the Board will be appointed by the Secretary. Pursuant to the provisions of Public Law 95-113, the Board shall, to the extent practicable, have ethnic, racial, and sexual balance. Membership on the Board will be composed of individuals with diverse capabilities distinguished by their knowledge and interest in plant genetic resources management.

In the event the Board tenure is over a period of years, partial rotation of membership would be practiced every two years to provide for continuity and broad representation on the Board.

The Assistant Secretary for Conservation, Research and Education will be Chairman. Dr. William L. Brown, President of Pioneer Hi-Bred International, Inc., Des Moines, Iowa, will be Vice Chairman. The Executive Secretary will be provided by the Science and Education Administration.

The Board shall report to the Secretary of Agriculture through the Assistant Secretary for Conservation, Research and Education, with particular assistance from the Director of the Science and Education Administration. The Director will provide support for the operations of the Board.

The functions of this Board cannot be performed in less than two years, and establishment of the Board is considered in the public interest. No existing committee can perform these functions, nor can the Department take effective unilateral action in view of the diversity of interested groups, and as such will serve an essential function.

This memorandum also serves as the charter for the Board.

In accordance with regulations for Federal advisory committees, the Board shall terminate two years from the date of this memorandum. The Department would like to (1) ensure continuity and increased involvement of the Board in genetic resources planning and coordination activities, (2) increase the association of the activities of the Board with genetic resource programs of State and private industry research organizations, and (3) expand the scope of the Board to relate to other kinds of genetic resources of great interest to agriculture. Accordingly, the Assistant Secretary for Conservation, Research and Education is directed to submit recommendations to me by July 1, 1978, about ways in which these objectives can be achieved.

Secretary's Memorandum No. 1875, dated July 3, 1975, is hereby superseded.

/signed/ Bob Bergland

Secretary of Agriculture

M E M O R A N D U M

TO: Secretary Bergland

FROM: National Plant Genetic Resources Board

The National Plant Genetic Resources Board was appointed by the Secretary of Agriculture in 1975 and reappointed in February 1978. NPGRB was a direct outgrowth of the alarm caused by the southern corn leaf blight which spread swiftly over the corn crop in 1969 and 1970 reducing yields 50 percent in some States and an estimated 15 percent nationwide.

The southern corn leaf blight of 1969-70 was not the first plant disease epidemic to strike an important crop but it was the first to shock a nation into the realization that many of our major crops rest on a narrow genetic base and consequently are highly vulnerable to attack by new forms of disease and insect pests. The southern corn leaf blight experience also resulted in the initiation of a series of studies designed to answer the questions as to how to reduce the probability of future epidemics and how to best cope with them should they occur. These are questions to which the NPGRB has addressed itself since 1975.

The accompanying report describes a seven phase program for minimizing genetic vulnerability which, if implemented, would make possible the proper conservation and utilization of the vast reservoir of plant germplasm. The total germplasm would probably contain the traits (genes) required to successfully cope with most pest problems, and its use would greatly increase the genetic base of those crops the nation depends upon for most of its food and fiber.

Examples of what might be expected to be accomplished through the program herein described are:

1. Pest management by genetic means.

Through the years agriculture has depended largely upon the use of chemical pesticides to control insects and diseases of plants. The system has been reasonably effective but the effects of some of the more persistent chemicals on the environment have now become a matter of national concern. The safest alternative to the chemical control of pests is the development and use of genetically resistant cultivars. These are developed by conventional breeding techniques. The sources of resistance are frequently found only in "exotic" varieties -- those found only in other parts of the world. Examples of the successful use of this method are green bug resistance in sorghum, anthracnose and head smut resistance in sorghum derived from tropical sorghums of Africa, and resistance to corn leaf blights from materials introduced from South Africa and South America.

2. Food quality and safety.

Most plant breeding has been directed toward the improvement of yielding ability and other agronomic traits that affect yields either directly or indirectly. Increased attention needs to be given to nutritive quality and food safety. To do so effectively requires the screening and evaluation of a broader range of germplasm than is present in the normal arsenal of materials with which breeders work. Expanded research in the area of food quality and safety would be an integral part of the program recommended in the accompanying report.

3. Increase in genetic diversity.

For various reasons the farmer, processor, distributor, and consumer demand uniformity in crop varieties and food products. The plant breeder has met these demands for uniformity but in so doing has decreased the genetic diversity of our major crop species. Unfortunately, a decrease in genetic diversity is frequently accompanied by an increase in genetic vulnerability and an increased risk of economic loss caused by some new parasite, insect pest, or unusual environmental stress. It is imperative, therefore, that attempts be made to restore a necessary measure of genetic diversity through the use of new and unrelated sources of germplasm.

The central point is that the conservation and use of plant genetic resources through the application of classical plant genetics and breeding, as shared among State, Federal, and industry groups, has been and continues to be a most cost effective investment of public and corporate funds. In recent years public support for this research has declined while newer, more glamorous trends have enjoyed high priority. Our fundamental appeal is that the tried and true should not be abandoned in favor of newer, but only potentially useful approaches.

RECOMMENDATIONS

1. The Board recommends that the Department assign high priority to the reestablishment of U.S. crop authorities. This is not a priority that requires a new budget. It entails the formation of committees (or the use of appropriate existing committees) under the jurisdiction of Science and Education Administration to (1) monitor breeding progress nationally and internationally, and (2) make recommendations for implementing the work broadly outlined in the Board's report.

2. We also recommend that high priority be given to additional support for the genetic improvement of cultivated crops. This recommendation does require budget and personnel to work on basic genetics, taxonomy, cytology, developmental breeding, and new methods to evaluate materials for food quality and safety, as well as resistance to pest and environmental stresses.

We urge that these two recommendations (the reestablishment of the U.S. crop authorities and increased support for the traditional aspects of breeding and genetics) constitute a primary budget thrust in 1981. We believe such a budget package could be developed through the regular USDA-SEA budget process with funds for implementation going directly to Agricultural Research and Cooperative Research.

January 11, 1979

ABBREVIATIONS

AR - Agricultural Research

ARPAC - Agricultural Research Policy Advisory Committee

CR - Cooperative Research

GRIP - Germplasm Resources Information Project

IBPGR - International Board for Plant Genetic Resources

LISA - Laboratory for Information Sciences in Agriculture

NAS - National Academy of Sciences

NIH - National Institutes of Health

NPGRB - National Plant Genetic Resources Board

NPGC - National Plant Germplasm Committee

NPGS - National Plant Germplasm System

NRC - National Research Council

NSF - National Science Foundation

NSSL - National Seed Storage Laboratory

SEA - Science and Education Administration, U.S.D.A.

USAID - United States Agency for International Development

SUMMARY

Most food and fiber crops produced in the United States have their origins from the plants brought to this country by the earliest settlers and, in more recent times, by plant explorers.

The United States has a long history of plant introduction. It evolved through various stages beginning with American consuls overseas who sent back seeds of useful plants to the United States. The present National Plant Germplasm System is a coordinated network of institutions and agencies (State, Federal, and private) working cooperatively to introduce, maintain, evaluate, catalog, and distribute plant germplasm.

The success of modern crop varieties, the explosion of the world population, and the disturbance to ecosystems by the industrial revolution have tended to reduce the amount of genetic variability in plant genetic resources.

Improvement of crop varieties through plant breeding has been a major catalyst of the agricultural revolution of this century. Breeding to meet constantly evolving requirements for higher yield; resistance to insects, diseases and environmental stresses; better nutrition; safer food; and biomass production, demand a well planned system for the conservation, maintenance, and utilization of a wide assortment of plant genetic resources. Such a system is crucial to the future well-being of this country and responsibility for it must rest squarely with the U. S. Department of Agriculture.

Genetic vulnerability is the term used to describe epidemic losses, which happened, for example, with southern corn leaf blight in 1970. No program can reduce the probability of epidemics to zero; however, the best approach to lowering the probability or solving the problem, should one arise, is to have a sound program in all seven phases of the research and development activities for conserving and using plant genetic resources.

This report describes a seven-phase program for conserving and using plant genetic resources. The program includes plant introduction, classification, screening, basic genetics, developmental research, applied research, and finally production of seeds of improved varieties for sale to farmers.

This seven-phase program represents an outstanding example of State, Federal, and private industry cooperation and planning. The program has been and continues to be extremely successful, but it tends to receive low priority ratings in the budget process in spite of the fact that it is fundamental to all agricultural missions. Plant germplasm resources and their use are central to a multitude of national goals, including increasing exports; boosting farm income and enhancing the national economy; protecting the environment; conserving energy; helping with soil conservation; minimizing cost of food; providing safe, nutritious food; developing pest-resistant crops and crops better adapted to less favorable environments, and minimizing cost of building materials and other forest products.

This report also presents the following objectives with specific recommendations for achieving them:

I. Improvement of the U.S. National Plant Germplasm System.

II. Reestablishment of Preeminence of U.S. Crop Authorities.

III. Genetic Improvement of Cultivated Crops.

IV. Support of the National Plant Genetic Resources Board.

V. Liaison with Other Organizations.

PLANT GENETIC RESOURCES: CONSERVATION AND USE

RECOMMENDATIONS

I. Improvement of the U.S. National Plant Germplasm System

1. Recognize that the seven-phase program described in the NPGRB report of 1978 is an outstanding example of State, Federal, and industry coordination and cooperation for the achievement of common national goals of high priority.

   Recognize that, while nitrogen fixation, photosynthesis, and genetic engineering now enjoy favorite trendword status and they are important research areas, genetics and plant breeding work, using established methods, should be ranked as high or higher in priority.

   Recognize that plants developed by recombinant DNA technology or protoplast fusion must be used in the seven-phase program before agricultural benefits are realized.

   Assign high priority to the seven-phase program outlined in this report in the FY 1980 and subsequent budgets.

2. Authorize SEA, in cooperation with NSF, to explore policies and procedures necessary to provide adequate continuing support for the acquisition, maintenance, and distribution activities involving genetic stock collections of all significant crop species.

3. Support AR- and CR-SEA in the following ongoing programs recommended by the NPGC:

   (1) Construct a system of clonal repositories for fruit and nut crop germplasm.

   (2) Continue the development and implementation of a comprehensive information system. This work is currently underway and is called the NPGC-GRIP project.

4. Establish a temporary committee under the Joint Council for the purposes of (1) estimating U.S. manpower requirements in germplasm biology, and (2) recommending an adequate national training program in germplasm biology consistent with need. We would hope this committee could complete its report by May 1979.

II. Reestablishment of Preeminence of U.S. Crop Authorities

5. Establish and finance a committee, or use an existing committee, of genetic resource experts on each important crop (or groups of minor crops where that seems desirable) to:

    (1) Monitor the collecting and breeding progress of other nations and/or international agricultural research institutes.

    (2) Make specific recommendations on introductions and plant explorations.

    (3) Recommend maintenance procedures and responsibilities.

    (4) Suggest research programs to make maximum use of germplasm resources for the benefit of producers and consumers in the United States.

    (5) Periodically report (at least every five years) on the state of efforts in the United States and the world to improve productivity of the species or to tailor materials for potential world market. (Out of such work should emerge U.S. authorities on each significant species, individuals with both national and international perspectives. The U.S. is now extremely weak in this regard.)

    (6) Form such commodity committees under jurisdiction of SEA, USDA. (Formation of such crop committees is one of the more important and immediate actions which could be taken by this administration to assure that producers and consumers in the United States benefit to the maximum from both the scientific effort in the United States and that now developing so rapidly abroad.)

III. Genetic Improvement of Cultivated Crops

6. Assign high priority both to developmental breeding and to understanding of genetic systems of each important crop species.

    Establish crop improvement teams with at least one plant breeder, pathologist, and entomologist on each team. Some teams should also have a basic geneticist and soil scientist.

Provide scientists with technical help to screen, in both fields and laboratories, large numbers of stocks in the germplasm inventory.

Provide resources to rapidly and economically measure characteristics important in food safety, nutrition, pest resistance, and product quality.

Conduct research on the technology of evaluating materials for pest resistance and tolerance to environmental stresses.

Provide that the funds for this area of work be flexible and permit rapid expansion when new disease, insect, or stress problems arise. A strong backup program is necessary to offset the prevalence of vertical pest resistance in major crop cultivars.

7. Support and promote basic studies in genetics and other fields that contribute to an understanding of the genetic makeup of each significant crop species and their interspecific relationships.

IV. <u>Support of the National Plant Genetic Resources Board</u>

8. Take steps to extend appointment of the NPGRB beyond February 1980; do so in time to assure unbroken tenure of the Board.

Provide the Board with a full-time Executive Secretary with clerical staff and support.

Expand the scope of the NPGRB to include forest germplasm resources.

Coordinate the activities of the NPGRB with those of the IBPGR and other national and international programs. Invite a member(s) of IBPGR to attend NPGRB meetings.

V. <u>Liaison with Other Organizations</u>

9. Continue the close liaison among public agencies and with such organizations as the American Seed Trade Association, National Council of Commercial Plant Breeders, Association of Official Seed Certifying Agencies, and other organizations concerned with providing a reliable supply of improved, high-quality planting seed to the consuming public.

Encourage the NPGRB to maintain liaison with agricultural research foundations, industry, IBPGR, lesser developed countries, and others advancing the cause of American and world agricultural production.

I. INTRODUCTION

Lack of Native Crops in the United States

If American consumers were asked to live on food from crops native to the United States, they would probably be shocked that their diet was limited to sunflower seeds, cranberries, blueberries, strawberries, pecans, and not much else. Bread, cereals, potatoes, fruits, and vegetables would be missing from their tables. Tobacco would be available, but they would have no cotton or flax textiles for clothing and linens. If the United States had to import the food we eat and fiber used to clothe and house us, this would make our balance of payments for oil look small by comparison. Fortunately, we do not import food and fiber directly; however, resources that support our domestic food and fiber production are imported.

Without the systematic introduction and use of germplasm resources the average acre yield of corn could not have risen 320 percent from 1930 to 1975. Moreover, the energy required to produce the 1975 corn crop would have increased oil imports by millions of barrels if yield per acre had remained at the 1930 level.

Long History of Plant Introduction

In precolonial and colonial days the early settlers found few of the crops they had known in the Old World. The Indians grew some corn, beans, and squash; however, these crops had been brought into the future United States much earlier by Indian tribes from what is now Mexico.

In the early settlement days immigrants to the United States quickly learned that they had better bring seed with them. The U.S. Government early recognized this paucity of seed and encouraged the search for seed of adaptable crops. In 1819, American consuls overseas were asked to collect seed of useful plants and send them to the United States. From 1836 to 1862 the U.S. Patent Commissioner administered the introduction of plants. In 1862 the U.S. Department of Agriculture was established. Since that time various agencies of the U.S.D.A. have accelerated plant exploration and plant introduction activities.

The Current Challenge for Food and Fiber

The United States and the world face many agricultural challenges now and in the future. During the past 60 years the population of the world has grown from over a billion-plus to 4 billion. It has been predicted that the population may reach 6 or 8 billion by the end of this century.

Repeated studies have shown that if the human family expects to feed its burgeoning numbers, "We have to find in the next 25 years, food for as many people again as we have been able to develop in the whole history of man 'til now" (Jean Mayer 1975). In addition to this humanitarian aspect, bountiful and secure agricultural production is essential for the welfare and economic prosperity of nations.

Before the dawn of recorded history people began to become less dependent on hunting and foraging by turning to the cultivation of plants. Throughout the centuries plants judged to be superior were saved for propagating subsequent crops, some of which were doubtlessly chance or man-made hybrids. Thus, a vast number of "folk" varieties were developed in all parts of the world. Great genetic variability existed within and among these varieties. Moreover, that portion of species not chosen for cultivation generally survived in nature, because the pressure of the human population and advanced agricultural technology had not yet destroyed their natural habitats. In this century the situation that existed so long has changed and continues to change rapidly.

Professional plant breeding began 60 or 70 years ago with the rediscovery of Mendel's laws and the development of the chromosome theory of heredity. By applying these scientific principles breeders developed modern crop varieties generally highly uniform and specialized for yield, quality, and adaptation to specific environments. The constant release of improved varieties and the adcption of advanced production technologies resulted in remarkable increases in agricultural productivity. The superiority of these modern varieties over folk varieties led to their widescale adoption in this country and in other parts of the world. Many old varieties were abandoned with serious loss of these important plant genetic resources. Genetic resources in the wild as well as those in cultivation as folk varieties are rapidly disappearing.

Responsible agricultural leaders in this country and abroad have recognized for many years that plant genetic resources were being lost and that genetic variability among varieties was being reduced. The urgency of the southern corn leaf blight epidemic of 1970 shocked the nation into considering the conservation and proper use of plant genetic resources as activities of first importance to its continued well being.

Tragic epidemics have occurred since Biblical times. Recent examples are the Irish potato famine of the 1840's, the Ceylon coffee rust epidemic in 1870, the United States wheat rust epidemic in 1916 and the Bengal rice epidemics in 1942. The destruction of chestnuts several years ago and the current attack by the pathogen causing Dutch elm disease add to the list. Droughts in India, Africa, and our own Midwest and Far West in recent years emphasize that crops are vulnerable to stresses.

The term "genetic vulnerability" was coined to explain the southern corn leaf blight epidemic of 1970. In the genetic vulnerability of crops, uniformity is the key factor. The probability of an epidemic is increased when large

numbers of plants are genetically alike. If one becomes susceptible, all become susceptible.

Although genetic diversity offers some protection against epidemics it does not guarantee that one will not occur. Producers and consumers want improved varieties with high yields, good quality and uniformity of product. They want varieties that lend themselves to low production costs. Genetic diversity is sacrificed because everyone wants to grow the best variety. The farmers want to grow the variety that makes them the most money. The seedsmen and breeders want to breed the best variety and capture as much of the market as they can. Breeders tend to use the better varieties as breeding stocks for further advances, which in turn reduces the genetic variance among varieties. Mechanized farming requires uniformity of seeds, maturity, and plant height.

Breeders now tend to release varieties with greater genetic diversity within them than they formerly did when the "pure line" theory was more in vogue. This trend helps; however, genetic diversity within varieties planted, by itself, will not adequately minimize the risks. Genetic vulnerability may be minimized most effectively by a sound research program in each of the seven phases of the program described in this report. Thus, genetic vulnerability is not simply uniformity in the fields; it is related to such factors as our ability to respond quickly to unexpected conditions. Our ability to respond should be related to knowledge of the crops and their relationships to pests and physiological stresses.

In 1970 the fungus (Bipolaris maydis) causing southern corn leaf blight spread across the nation. Losses reached 50 percent in some States and 15 percent nationally. This threat to the existence of a major crop created so much alarm that the Agricultural Board of the NRC appointed a committee on Genetic Vulnerability of Major Crops. This committee considered (1) what caused the corn blight epidemic of 1970, (2) how vulnerable crops were to attacks by pests, and (3) what should be done to hold losses to low levels and reduce the probability of epidemics. The book "Genetic Vulnerability of Major Crops" was issued by the NAS in 1972. The chapter on "The Challenge of Genetic Vulnerability", said in part, "Two points are clear: (a) vulnerability stems from genetic uniformity; and (b) some American crops are on this basis highly vulnerable. This disturbing uniformity is not due to chance alone. The forces that produced it are powerful and they are varied. They pose a severe dilemma for the sciences that society holds responsible for its agriculture. How can society have the uniformity it demands without the hazards of epidemics to the crops that an expanding population must have?"

A partial answer to this question was provided in a special report by an ad hoc subcommittee of ARPAC, issued in 1973 by the U.S. Department of Agriculture and the National Association of State Universities and Land Grant Colleges. The subcommittee recommended that the Secretary of Agriculture appoint a National Plant Genetic Resources Board to assure the proper management of these national resources. A Board at this level was considered to be vital to the effective coordination of many efforts among public, private, and international groups.

In 1975 the Secretary of Agriculture established the NPGRB to advise him on national needs for the assembly, description, maintenance, and effective use of living resources in plant improvement programs. Secretary's Memorandum No. 1875 Revised, dated February 23, 1978, reestablished the Board.

Role of Plant Genetic Resources in Agriculture

Crop production can be improved in only two ways: (1) By improving the genotypes of the plants, and (2) by improving the environment through cultural practices and non-heritable protection from pests. All knowledge and practices must be channelled into these two mutually dependent avenues or they cannot influence production. Plant genetic resources are used in the first of the two ways to improve and sustain crop productivity.

Plant genetic resources extend from wild species to varieties in production. A program in agricultural research connects these extreme types of plant genetic resources. Because this work is scattered geographically, involves all crops and disciplines, and is shared by State and Federal agencies and industry, it is easy to miss the significance of the total program. The capability for the United States to carry out this work demands that the technical competence required in all areas of germplasm biology be assessed and that necessary steps be taken to insure its availability.

Genetic improvement of crops requires that plant genetic resources be collected, maintained, and used. The work may be divided into seven phases with the phases falling into a natural sequence, as follows:

(1) Collecting, maintaining, evaluating, documenting, and distributing plant genetic resources. This phase helps to provide the nation with the plant genetic resources to meet current and future needs. It is of primary interest to the NPGC.

(2) Understanding the genetic variability and geographic distribution of cultivated species and their taxonomic and cytological relationships with closely related species.

(3) Screening plant genetic resources for specific, desirable characteristics. This should be done in each relevant ecological region for such characteristics as pest resistance, maturity date, nutritive quality, photosynthetic efficiency, drought tolerance, adaptation to problem soils, and fruiting efficiency. Genes for accomplishing improvement objectives must be located; genetic variation for the characteristics must exist before progress through breeding can be made.

(4) Studying the genetic mechanisms controlling the inheritance of desirable characteristics. Such knowledge is required for determining breeding objectives, selecting parental materials, and choosing appropriate breeding methods.

(5) Combining genes from diverse sources into improved strains more useful to plant breeders. Genes for desirable characteristics are often found in stocks inferior to cultivated ones; they are seldom found within the same stock. This phase is sometimes called developmental breeding. It is a connecting link between basic and applied research, and it sorts out those objectives that have a high probability of success for applied breeding from a large number of possibilities.

(6) Breeding, releasing, and maintaining breeder seed of varieties and stocks of improved germplasm.

(7) Producing high-quality planting seed and distributing it to farmers. This is the ultimate objective of all the preceding phases because it makes available seeds (or other plant propagules) with the inherent capability for efficient production of high quality crops, well adapted to our environment and cultural practices, and with as much "built in" protection as possible from pests and environmental stresses.

These phases are best thought of as a continuum that sets up a gene flow from source to end use. Unless all phases are operating an imbalance or block develops. Continuous flow from phase to phase keeps high yielding varieties on the market; improves the quality of agricultural products; reduces dependence on pesticides, thus enhancing the environment; minimizes cost of production, and reduces vulnerability to pests and environmental stresses.

Society has great concern about the loss of species from the earth. The Endangered Species Act was passed to minimize the loss of species. The Nature Conservancy and other organizations are active in protecting life forms in preserves, zoos, and arboretums and in preventing environmental disturbances that may endanger the habitat of species. This is conservation at the species level. Many endangered species have no detectable use except that they are a part of the great interdependence of life forms in ecosystems. The disappearance of a species might cause an ecological shift unfavorable to esthetic values and even utility.

The NPGRB contends that society should be equally, if not more, concerned about the conservation of the genetic variability accumulated within economic species during the long evolutionary processes. After all, most of these species have demonstrated their usefulness since the dawn of agriculture. People are dependent on them for food, fiber, and some industrial materials for survival and on things of beauty for an enhanced quality of life. We will continue to encounter changing pest problems, changing concepts of food safety and human nutrition, growth in population, the need to grow crops in more environmentally stressed situations, and use of plants for biomass energy.

Plant genetic resources are maintained in four ways: (1) Most are maintained in natural ecosystems according to the "survival of fittest" principle. This material is just out there, with no inventory and no managed preservation

scheme. (2) Folk varieties are cultivated generally by small farmers in lesser developed countries where modern professionally bred varieties do not dominate the agriculture. (3) Collections and materials are assembled by private corporations, professional research scientists, private collectors, hobbyists and amateurs. (4) Permanent collections are maintained in the public interest by governments.

Problems with the first two categories have been discussed. The third system is notoriously subject to abandonment, because originally interested curators retire, administrators object to the expense of maintenance, and institutional land and facilities are relocated. The third category also has limited use, because it is difficult to know who has what where, and information on the items is disorganized and inaccessible. Early in its history the United States decided that the first three maintenance categories were not trustworthy enough to provide for the plant resources for the cultivated crop species. The present form of our national scheme for maintaining plant genetic resources is known as the National Plant Germplasm System. The system has evolved over time, particularly since the Research and Marketing Act of 1946 established regional and interregional plant introduction stations with joint Federal and State funding.

II. RESEARCH AND DEVELOPMENT ACTIVITIES FOR CONSERVING AND USING PLANT GENETIC RESOURCES

Phase 1. Collect, maintain, evaluate, document, and distribute plant genetic resources.

This phase has received substantial attention by SEA-AR and SEA-CR in recent years. The high priority assigned to this work was stimulated in part by (1) the previously mentioned reports of NAS and ARPAC, (2) the world interest in the issue as expressed by the IBPGR publication, "Priorities among Crops and Regions," (IBPGR was established by the Consultative Group on International Agricultural Research "to insure that genetic variability in economic species of plants is conserved so that it can be used by plant breeders and by research workers interested in the evolution of cultivated plants and of agriculture itself"), (3) the NPGRB established by Secretary's Memorandum No. 1875, dated July 3, 1975, (4) the recommendations of the NPGC, (5) symposia on genetic vulnerability and germplasm resources of the 1975 annual meeting of the Crop Science Society of America, and (6) numerous articles in popular and scientific publications.

Tangible evidence of action includes (1) much better funding and staffing for the NSSL, Ft. Collins, Colorado, (2) a budget item in SEA-AR for plant explorations that allows 6 to 8 expeditions per year, (3) increased support for Regional Plant Introduction Stations and curators of specified germplasm, (4) development of the NPGS, (5) approval of National Research Program (NRP No. 20160), "Introduction, classification, maintenance, evaluation, and documentation of plant germplasm", and of Special Research Program "Genetic

Vulnerability", (6) commitment by SEA-AR and SEA-CR to develop facilities, staff, and support for a nationally coordinated system of clonal repositories for fruit and nut germplasm, (7) a cooperative agreement between SEA-AR and LISA, Colorado State University, Fort Collins, for the development and implementation of a computer-assisted information system to service the NPGS, and (8) the SEA-CR competitive grant program on genetic vulnerability.

The NPGRB surveyed the status of germplasm collections in ten crops and found deficiencies in existing collections, inadequate support for official curators of germplasm, and inadequate training of personnel with skills and interest in germplasm biology. Doubtlessly an analysis of other crops would reveal similar deficiencies.

Phase 2. Understanding the genetic variability and geographic distribution of cultivated species and their taxonomic and cytological relationships with closely related species.

Knowledge of the genetic structure of cultivated plants and of their genetic relationships with closely related species is essential for effective planning and execution of plant improvement programs. Concepts of interspecific relationships are developed from basic studies in many disciplines: genetics, cytogenetics, biochemistry, morphology, distribution, and ecology. Such information is required for the sound and workable taxonomy needed to catalog and use the large number of accessions in germplasm collections.

Genetics. In the study of the genetic architecture of crop plant species, linkage groups are mapped for the most clearly expressed marker genes. Also investigated is inheritance of quantitative and cytoplasmically determined characters. The methods exploit both spontaneous and artificially induced mutations. Studies of cellular genetics promote an understanding of the basic genetic makeup of a plant species and provide genetic lines that have immense potential for solving problems in physiology, morphological development, and plant biochemistry. These investigations are coordinated with studies of inheritance of economic traits visualized in Phase 4 and are inevitably integrated with those of cytogenetics.

Exotic accessions are also studied to determine their crossability with crop species and the characteristics of hybrids that might thereby be produced. These investigations determine the limits of hybridization, the nature of barriers to genetic exchange, fertility and viability of F_1 hybrids and later generations, and the extent of genetic and cytoplasmic differences between the parents. Not only is such information vital to biosystematists, but it also informs the plant breeder of the feasibility of using such accessions successfully.

Cytogenetics. Genetic analysis of a species is aided by coordinating it with the study of chromosomes. The chromosomal composition of a species is analyzed by employing cytological deviations from normal. Wild forms of the cultivated species and related species are routinely analyzed for chromosome number and morphology as aids in understanding natural relationships and the nature of barriers to gene exchange between taxa. Studying the relationship

of meiotic chromosome pairing and fertility in diploid and polyploid hybrids often clarifies the nature of hybrid sterility and leads the way to the most efficient use of exotic germplasm.

Maintenance of genetic and cytogenetic special stock collections from economically important crop species is necessary for progress in research. The special stocks are also used in physiological and biochemical studies that are concerned with an understanding of plant growth and developmental processes. A recent NAS-NRC report entitled "Conservation of Germplasm Resources: an Imperative" recommends "that support by the NSF of important genetic stock centers and maintenance of germplasm resources through support from the NIH Division of Research Resources is very helpful and should be continued and expanded. Other agencies should consider adopting the policy of direct support of genetic stocks to assure their continued availability..." Genetic stock collections are uniquely useful as research tools and are not to be confused with the general germplasm collections that provide genetic variability for crop improvement. Currently support of genetic stock centers for crop species is divided between SEA and NSF, with little formal planning or collaboration. It would be desirable for SEA and NSF to review the problem of genetic stock maintenance in order to develop a policy of financial support adequate to the task. Such a policy might involve either transfer of funds or reassignment of responsibilities for certain stock centers.

Biochemistry. The literature has many examples of the use of biochemical constituents for studies of the classification and evolution of plant species. For example, differences in terpene content are of systematic interest in the pines as are storage proteins in the legumes. Besides aiding systematists, such determinations may reveal new sources of compounds with nutritional or industrial significance. The degree and pattern of variability of isozymes have already permitted analysis of interspecific and subspecific relationships. The nature of pest resistance, food safety, and nutritional quality are largely determined biochemically.

Morphology. Morphological characters furnish the data for classical taxonomy and often provide the only criteria for classification of herbarium specimens and field identifications. Qualitative characters are observed and quantitative characters are measured in the form of the whole plant or its parts. In plant germplasm assemblages the collection of such data is usually limited to characters of systematic and economic importance, but studies integrating morphology with the genetics are mutually beneficial.

Distribution. Information concerning geographic distribution often directs collectors to critical areas and distinguishes between wild and domesticated traits. The area of cultivation usually extends far beyond the native range; such differences can be significant in relation to the presence or absence of pests. Geographic isolation frequently expedites the differentiation of new biotypes and thus can be important in plant collecting expeditions. Weedy races may accompany the cultivated forms and play a significant role in the evolution and use of plant species.

Ecology. The distribution of a plant taxon is determined by its ecological preferences. Reproductive isolation can play an important role in evolution and thus be of interest to the systematists. Observations of the responses of plants to temperature, light intensity, photoperiod, soil type, and other factors in their native habitats and in first-trial plantings can give important information for the effective use of plant germplasm resources.

Continued research in these areas can provide the following benefits: (1) Determine the nature of genetic control of certain characteristics of interest to plant breeders, (2) reveal the opportunities and limitations of gene transfers from accessions to acceptable cultivars, (3) yield clues on the presence of useful characters, (4) ascertain the origin and sites of domestication, and (5) formulate a sound basis for classification.

Phase 3. Screen plant genetic resources for specific, desirable characteristics.

As plant genetic resources are collected or produced, they need to be screened to determine what characteristics they possess that are desirable for agriculture. As characteristics are identified, the germplasm is used as parental material for developing new genetic complexes. Each variety or population is characterized by a specific genotype or gene frequency. When crosses are made between strains of divergent origin, the F_1 generation may exhibit hybrid vigor and the F_2 generation of such hybrids may display genetic variability caused by the recombination of genetic material in new and unique genotypes. This provides further opportunity for the isolation of more efficient and desirable types.

Indepth screening is done by the users rather than the maintainers of the plant genetic resources. The potential value of germplasm collections depends upon the efficiency of techniques available or still to be developed that are designed to characterize the genetic differences among the individual items of a collection.

Ideally indepth screening should be done by crop-improvement teams made up of breeders, entomologists, pathologists, and soil scientists. Because of close ties with farmers, such a team would be aware of problems arising from an outbreak of a new pathogen or race or a new destructive insect. They could identify the causal agent involved and establish either the suitability of existing inoculating techniques or, if necessary, devise and evaluate new procedures. Such a team should have the field and laboratory facilities and the crop expertise necessary for success. The procedures necessary in any search for resistance are likely to be required to transfer such resistance to commercially useful varieties.

This team approach has a long history of success in discovering sources of resistance, for example, downy mildew in corn, the corn viruses, the several smuts and rusts of small grains, late blight in potatoes, spotted alfalfa aphid, and many others. Within the past 40 years the improvements in pest resistance of our major cultivated crops have been an important factor in increasing efficiency of our agricultural production.

Germplasm may also be screened for attributes other than disease or insect resistance. Possible attributes include: morphological variations contributing to increased yield; variation in quantity and quality of proteins, amino acids, or fats; the absence of toxic substances such as trypsin inhibitor in soybeans. Such a list could be extended indefinitely. Screening for desirable attributes of the type listed may require specialized equipment. Fortunately both apparatus and techniques are available for measuring many attributes of interest. Few of the procedures now available, however, have the capability or flexibility for handling the large numbers required for effective progress.

Phase 4. Study the genetic mechanisms controlling the inheritance of desirable characteristics.

The discovery of desirable characteristics in the screening phase is the first step in the use of the germplasm resource. If an effective strategy for using specific characters is to be developed, genetic analysis of the inheritance of specific traits and the quantitative analysis of population variability are essential prerequisites.

Breeders are urged to select various objectives by soil scientists, nematologists, pathologists, entomologists, and physiologists as well as farmers, food scientists, trade associations, processors, and consumers. Breeders face a bewildering choice of potential parental materials, and the science of plant breeding offers many breeding methods. If a good choice of objectives, materials, and methods is to be adopted, information is needed on the inheritance and genetic variability of desirable traits.

Phase 5. Combine genes from diverse sources into improved strains more useful to plant breeders.

Genes for desirable characteristics are usually found in stocks unsuitable for cultivation. Resistance to pests, ability to stand cold or drought, high protein content, improved amino acid balance, early maturity, and a host of other desirable features are seldom found together in stocks as an ensemble of the characteristics required for successful cultivation. Successful varieties have to have a composite of characteristics that makes them more profitable to grow than varieties already on the market. Building insect and disease resistance into superior varieties, a continuing struggle of science against nature, requires long-term, continuous work by competent entomologists, pathologists, and breeders. Such work is sometimes called developmental breeding, or exploratory research. This work connects germplasm collection, screening, and genetic analysis with applied breeding. From a large number of objectives that might be pursued, it sorts out those that have a high probability of success. It prevents the more applied programs from diverting their limited resources and time into unproductive efforts.

The work of the first four phases produces breeding materials that possess unique characteristics or unique combinations of genes with reasonably good agronomic or horticultural features. It is becoming more and more

common for Federal and State agencies to release improved breeding stocks noncommercially so that appled breeders from any public, private, or lesser developed country may use the material at this stage.

Adaptation, or its lack, becomes an important problem in the transfer of desired traits from an exotic or wild strain to a commercially useful variety. Even though the genetic basis of the desired trait may be simple, the combination of specific characteristics with all other genetic traits affecting adaptation and field performance may result in a very complicated genetic system. The degree of complexity varies with the degree of dissimilarity of the parents used. Here, again, it appears that evaluation as well as screening can best be accomplished by a crop improvement team. It is in this phase that the recurrent evaluation of resource material being advanced toward cultivation becomes of utmost importance.

Evaluation of the relative merits of candidate strains and varieties is most often based on the results of a series of replicated performance trials over a period of years at several locations. The material is subjected to a sample of the environments that future varieties are most likely to encounter. This includes variation in soil type, nutrition levels, diseases, pests, weather, cultural practices, and harvesting methods. Although this type of field evaluation is still the best predictor of the future performance of any new variety, scientists often resort to evaluations in controlled environmental conditions. This is done to reduce the tremendous variation in weather and infestations that nature provides. For example, estimates of disease resistance are more reliable from artificial inoculations than from natural field conditions. Cold tolerance may be investigated in a temperature-controlled greenhouse or growth chamber.

Phase 6. Breed, release, and maintain breeder seed of varieties and stocks of improved germplasm.

The germplasm resource base for any crop involves a diverse assemblage of materials which may be roughly grouped as follows: (1) Currently useful varieties, (2) the very sizable reservoir of adapted but not currently utilized materials, (3) exotic and usually unadapted materials, and (4) the wild and weedy relatives. The problems relating to use increase in complexity with this progression. Plant breeding progress is most readily achieved when efforts can be confined to materials in groups one and two. Necessity, however, may require the use of materials from groups three and four.

Varieties are basically improved through a system of germplasm resource management. However, the majority of plant breeding experience and its foundation in quantitative genetic theory is based on studies with varieties and other adapted materials. The use of exotic and wild material poses a number of special problems for which neither theoretical nor practical answers are adequate. Recently funds for collecting and maintaining germplasm have been increased. These are necessary endeavors; however, if we are to move from a museum type of activity to one that recognizes vigorous utilization, adequate continuing support must be provided for crop improvement.

Crop yields in the United States over the past 45 years (1930-1975) have been remarkably upward. The following table shows the average yields of some field crops and major vegetables, as recorded in Agricultural Statistics, U.S. Department of Agriculture. The percentage increases from the original values range from 33 to 413 percent or about 1 to 9 percent per year on the average.

Average Yield Per Acre

	1930	1975	Unit	Percent increase
Wheat	14.2	30.6	Bushels	115
Rye	12.4	22.0	Bushels	77
Rice	46.5	101.0	Bushels	117
Corn	20.5	86.2	Bushels	320
Oats	32.0	48.1	Bushels	50
Barley	23.8	44.0	Bushels	85
Grain Sorghum	10.7	49.0	Bushels	358
Cotton	157.1	453.0	Pounds	188
Sugarbeets	11.9	19.3	Tons	62
Sugarcane	15.5	37.4	Tons	141
Tobacco	775.9	2011.0	Pounds	159
Peanuts	649.9	2565.0	Pounds	295
Soybeans	13.4	28.4	Bushels	112
Snap beans	27.9	37.0	Cwt	33
Potatoes	66.0	253.0	Cwt	283
Onions	159.0	306.0	Cwt	92
Tomatoes:				
(Fresh market)	61.0	166.0	Cwt	172
(Processing)	4.3	22.1	Tons	413
Hops	1202.0	1742.0	Pounds	45

A graph of average annual yields for each crop would have many ups and downs, influenced primarily by the weather; however, the trend has been steeply upward. Some crop yields are apparently beginning to plateau. Consumer demands require that we achieve equivalent or better gains in the next 45 years. Increased research on the biological processes of plants and plant pests is required to put genetically superior crops in the field and protect them against pests and environmental stresses.

Factors influencing the yield of a modern crop variety are complex. Fundamentally, yields per unit input of land, labor, and energy can be increased by breeding and crop management. The proper integration of genetic potential with insect and disease control, weed control, use of fertilizer and irrigation, timely and efficient cultivation and harvest, and other management activities are essential to continued yield increases. As crop production systems increase in complexity, genetic yield potential must keep pace. However, the genetic diversity must also be broad enough to avoid losses from pest outbreaks and to minimize the effects of annual weather fluctuations. The weakening of a single component may greatly depress overall yields, as illustrated by the corn blight situation in 1970.

Phase 7. Produce high-quality planting seed and distribute it to farmers.

This final phase of germplasm resources management has increasingly become a function of the commercial seed industry. The function of the seed trade is to supply farmers with an uninterrupted source of improved, high-quality planting seed. Some segments of the industry also support extensive breeding programs and thereby contribute to the objectives outlined under phases 5 and 6. However, the industry is not in a position to assume responsibility for many of the fundamental research objectives of germplasm management described in phases 1 through 4. On the contrary, the research efforts of industry have been and are likely to continue to be concentrated in those areas of practical plant breeding designed to produce the maximum number of commercially acceptable varieties in a minimum amount of time. To provide answers to fundamental breeding questions, increased support of the public research institutions is essential.

The cooperation between the public institutions engaged in the genetic manipulation of plant germplasm and the private seed industry is unique to the United States. Over the years the two groups of organizations have arrived voluntarily at a logical division of labor that includes minimal duplication of effort. The complementary nature of the relationship has served American agriculture well. The need for this kind of cooperation is as great today as at any time in the past. Each crop improvement program of industry and the public agencies does not need all seven phases; the nation itself needs all phases. This program can be a model for the national sharing of the workload among State and Federal agencies and private industry.

III. RESEARCH PRIORITY FOR PLANT BREEDING

In a recent "white paper" entitled "Research Priorities in Plant Breeding," Sprague, Alexander, and Dudley emphasized that successful plant breeding feeds the world. Recently, planning reports and the popular press have suggested that proven plant breeding methodologies will be replaced by genetic engineering. The "white paper" states that:

1. Classical plant breeding has been successful.

2. The limits to crop improvement through classical plant breeding have not been attained.

3. The heritable variation necessary for long-term improvement exists in our crops.

4. Effective utilization of variation requires a plant breeding approach.

5. Genetic engineering is a potentially useful tool that must have concurrent use of plant breeding techniques if it is to be effectively applied.

The broad field of genetic engineering now receives a high priority rating. The field holds some promise and unquestionably deserves support. The high priority rating is questionable, however, if the research is to be achieved through neglect of those disciplines that continue to improve plant performance and offer promise for the future. Even if new products are developed by genetic engineering techniques, the use of them will be accomplished through conventional crop improvement programs. Continuing progress in improving the performance of crops cannot reasonably be expected unless this relation is understood and implemented.

Budget justifications for plant breeding encounter difficulties. The plant breeding effort is shared by State, Federal, and private enterprise, and the work is scattered geographically and fragmented by commodities. Budget proposals look too much like "shoring up" of old programs that has been given the lowest of priorities recently. Plant breeding does not enjoy any trendword popularity, and component parts of the total system are often rated out of context.

Since the term "genetic engineering" has been coined, claims have continually been made that new techniques developed in the prokaryotes (bacteria, viruses)--for example, cell culture, protoplast fusion, and plasmid modification and transfer--hold great promise for both plant and animal improvement. These claims have been accepted by some and accorded a higher priority in research funding than that given conventional methods of breeding.

Uncritical acceptance of the potential importance of the new "genetic engineering" techniques, requires the denial of one or more of the following facts:

1. Efficiency of crop production is of short-term importance to American agriculture; the agricultural applications of genetic engineering are admittedly long range.

2. Plant breeding has made, and continues to make, genetic advances in crop productivity and quality.

3. Past successes in plant breeding have not exhausted genetic variability to the point that little progress can be anticipated in the future; much useful variability exists in domestic and exotic germplasm.

IV. CROP COMMITTEES

During recent decades, massive resources have been directed to support the improvement of the major food commodities worldwide. Support of a network of 10 international agricultural research institutes, most organized on a crop or animal commodity basis, has increased from about $15 million in 1972 to about $90 million in 1978. Concurrently, a number of foreign national agricultural research systems have been strengthened at an annual cost several times that invested in the international institutes; most of them also are organized on a commodity basis. Most receive substantial financial support from the United States, either directly through USAID or indirectly through the international banks. Most international agricultural research is organized around commodities; for the United States to be informed and influential about developments abroad, we should have strong commodity committees comprising authorities in plant breeding, plant pathology, entomology, and other relevant fields.

The United States should develop a cadre of national and international commodity experts in USDA and the State systems. Such individuals should have wide knowledge to keep the United States at the forefront of international efforts.

There should be a separate national committee for each crop or group of crops of significance to American agriculture. SEA, USDA could provide control leadership and support. In most cases the committee leader should be a plant breeder or geneticist of high national standing. The mandates of each committee should include:

1. Development of a strategic overview of progress in the United States with each commodity identifying strengths and weaknesses of the national scientific efforts on that species and recommending means of organizing activities that would benefit from national cooperative work. Particular attention should be given to plant breeding and genetics and to activities on disease and insect resistance and other means of pest control.

2. Development of an ever-improving understanding of foreign scientific developments on the crop in question identifying and describing implications for science and agriculture in the United States.

3. Providing periodic reports on national and international developments with the species, with statements of implications for the United States and recommendations for strengthening work, either in this country or in institutions abroad receiving major support from this country.

V. PERSONNEL REQUIREMENTS

Qualified scientists are needed to estimate the U.S. manpower requirements in germplasm biology. Current estimates of national need are lacking in the private and public sectors. An estimate of manpower requirements has been made by and for the USDA, but this estimate is for such broad categories as "soil scientists," "plant pathologists," and "agronomists." It does not delineate the proportion required within any group for germplasm biology.

The needs must be identified for the private, public, and possibly international sectors. Estimates should be compiled for the near future (5-10 years) and for the long term (more than 10 years). This documentation should include areas of germplasm biology that are of current critical importance (e.g., host-parasite biology, population biology, cytogenetics, evolution, breeding methodology) and of potential importance (e.g., cellular and subcellular biology of flowering plants, cell and tissue culture, viral transfer of genetic material).

Research program development in the United States accelerated immediately after World War II. Many of the scientists recruited at that time are now reaching retirement age. Many changes in personnel must take place during the next 10 years. The present time is therefore critical for reviewing manpower requirements and for reconsidering program priorities at all levels. In spite of the expansion of research during the past 30 years, the current output of qualified personnel may not be adequate to meet the needs of the near future. The number of training centers, particularly in plant genetics, has diminished, and the possibilities of extinction in certain areas of expertise are real.

VI. FUTURE OF NPGRB AND ITS REQUIREMENTS

The NPGRB should:

(1) Identify relevant research areas needing funding.

(2) Suggest how regulatory agencies responsible for detecting breakdowns in agricultural systems might more efficiently meet national needs (e.g., detection of potential disease epidemics in the United States and abroad).

(3) Help develop guidelines on the competitive grants program.

(4) Serve as a principal arm for the Secretary in studying germplasm resources and in recommending use of breeding

material, thereby helping to insure that appropriate measures are taken to avoid catastrophes caused by narrowing the germplasm base during the improvement of crop plants.

(5) Change its membership in a regular and systematic way in order to bring fresh ideas and new experience to the task.

To accomplish its purposes the NPGRB should be assured of an existence long enough to meet the objectives so urgently needed by the nation. The operations of the NPGRB would be greatly enhanced if it had the services of a fulltime, permanently assigned Executive Secretary with clerical staff and a budget sufficient for travel, publication costs, and occasional conferences or symposia.

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